

Final Technical Report

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Principal investigator/Primary contact: Natalia Ruppert
Alaska Earthquake Center, Geophysical Institute
PO Box 757320
Fairbanks, AK 99775-7320
Phone: 907.474.7472
naruppert@alaska.edu

Co-Principal investigator/Alternate contact: Michael West
Alaska Earthquake Center, Geophysical Institute
PO Box 757320
Fairbanks, AK 99775-7320
Phone: 907.474.6977
mewest@alaska.edu

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1. Abstract

The Alaska Amphibious Community Seismic Experiment (AACSE) comprised 75 ocean bottom seismometers and 30 land stations and covered about 650 km along the segment of the subduction zone that includes Kodiak Island, the Alaska Peninsula and the Shumagin Islands between May 2018 and September 2019. This unprecedented offshore dataset provided an opportunity to compile a greatly enhanced earthquake catalog by both increasing the number of detected earthquakes and improving the accuracy of their source parameters. We use all available regional and AACSE campaign seismic data to compile earthquake catalog for the region between Kodiak and Shumagin Islands including Alaska Peninsula (51-59N, 148-163W) between May 12, 2018 and August 31, 2019. We apply the same processing and reporting standards to additional picks and events as the Alaska Earthquake Center currently uses for compilation of the authoritative regional earthquake catalog. Over 7,200 events (both newly detected and previously reported) have been processed with additional data. We added about 30% more events, 60% more phase picks, and lowered the magnitude of completeness by about 0.2 units in some areas. Most of the newly detected earthquakes are in the 2018 M7.9 Offshore Kodiak earthquake aftershock region, as well as under the Kodiak Island and the Alaska Peninsula. All data has been published in public data archives.

2. Report

2.1. Personnel and timeline

The project plan assumed hiring of student assistants to work on the earthquake data analysis. Unfortunately, the project started at the same time as the COVID-19 pandemic began to spread through the United States and the world. University of Alaska Fairbanks went into remote operations in March 2020 making it difficult to hire, train, and retain students. Eventually, we were able to adapt to the new reality of remote work. Out of 4 students that worked on the project, 2 stayed on through the end. Due to delays in hiring, training and problems with retaining initially hired students the project has been delayed. As a result, we requested a 90-day no-cost-extension twice therefore extending the project completion date to June 30, 2021.

2.2. Station metadata and waveforms

In the beginning of the project we downloaded station metadata for about 100 sites and corresponding waveforms from seismic and pressure sensors from IRIS Data Management Center (DMC, <https://ds.iris.edu/ds/nodes/dmc/>). Next, the data has been merged into our in-house waveform archive and station database. This process took more than one attempt since we discovered some problems with station metadata that were contributed by other partners on the project. It took some time for the partners to verify and update the metadata, which again delayed our data processing efforts by a few weeks.

2.3. Earthquake processing

2.3.1. Setting up earthquake detections

First, we worked on identifying the best set of parameters for running seismic phase detection routines. We tested several options for filters, signal-to-noise ratios, and detection window lengths. We settled on 3 different sets of parameters for ocean bottom broadbands, land-based broadbands, and deep pressure gauges, correspondingly.

Land based station parameters:

```
thresh      3.5  # detection SNR threshold
threshoff   2.0  # detection-off SNR threshold
det_tmin     2.0  # detection minimum on time
det_tmax    10.0  # detection maximum on time
  &Arr{
    sta_twin   1.0  # short term average time window
    sta_tmin   1.0  # short term average minimum time for average
    sta_maxtgap 0.5  # short term average maximum time gap
    lta_twin   10.0 # long term average time window
    lta_tmin   5.0  # long term average minimum time for average
    lta_maxtgap 4.0  # long term average maximum time gap
    filter     BW 2.0 4 8.0 4
  }
```

Ocean bottom station parameters:

```
thresh      4.0  # detection SNR threshold
threshoff   2.0  # detection-off SNR threshold
det_tmin     2.0  # detection minimum on time
det_tmax    10.0  # detection maximum on time
  &Arr{
    sta_twin    0.75
    sta_tmin    1.0
    sta_maxtgap  0.75
    lta_twin    10.0
    lta_tmin    5.0
    lta_maxtgap  4.0
    filter      BW 4.0 4 7.0 4
  }
```

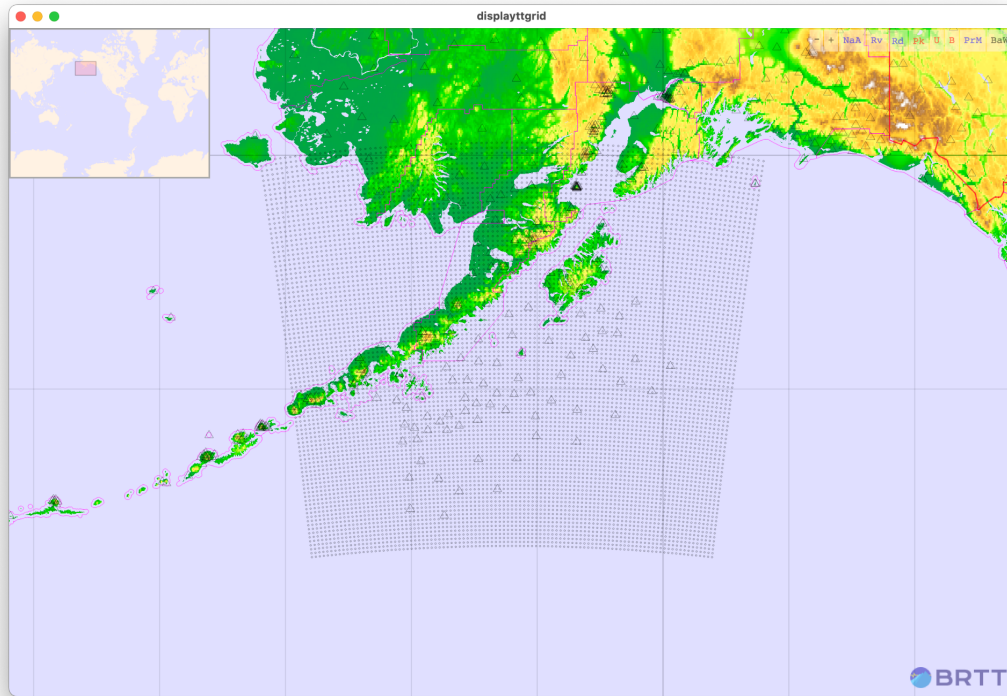
Pressure gauge parameters:

```
thresh      3.0  # detection SNR threshold
threshoff   2.0  # detection-off SNR threshold
det_tmin     1.0  # detection minimum on time
det_tmax     5.0  # detection maximum on time
  &Arr{
    sta_twin    0.5
    sta_tmin    1.0
    sta_maxtgap  0.75
    lta_twin    20.0
    lta_tmin    5.0
    lta_maxtgap  4.0
    filter      BW 4.0 4 0.0 0
  }
```

We then designed and tested travel time grids to be used for association of detected arrivals into potential hypocenters. After a number of tests, we decided to use 2 grids, one for 0-50 km depth with 5 km intervals and another for 60-260 km depth with 10 km intervals down to 100 km depth and 20 km intervals for farther on (Figure 1a,b). Both grids had horizontal node spacing of about 10 km.

And lastly, we identified stations with bad data quality or timing issues and removed them from our auto-detection lists. Noisy sites tend to produce too many false detections resulting in bogus events that increase workload on student analysts. Moreover, after evaluating automatic detection on pressure gauge channels we decided not to use them for auto-detections. These channels tended to produce too many false triggers.

(a)



(b)

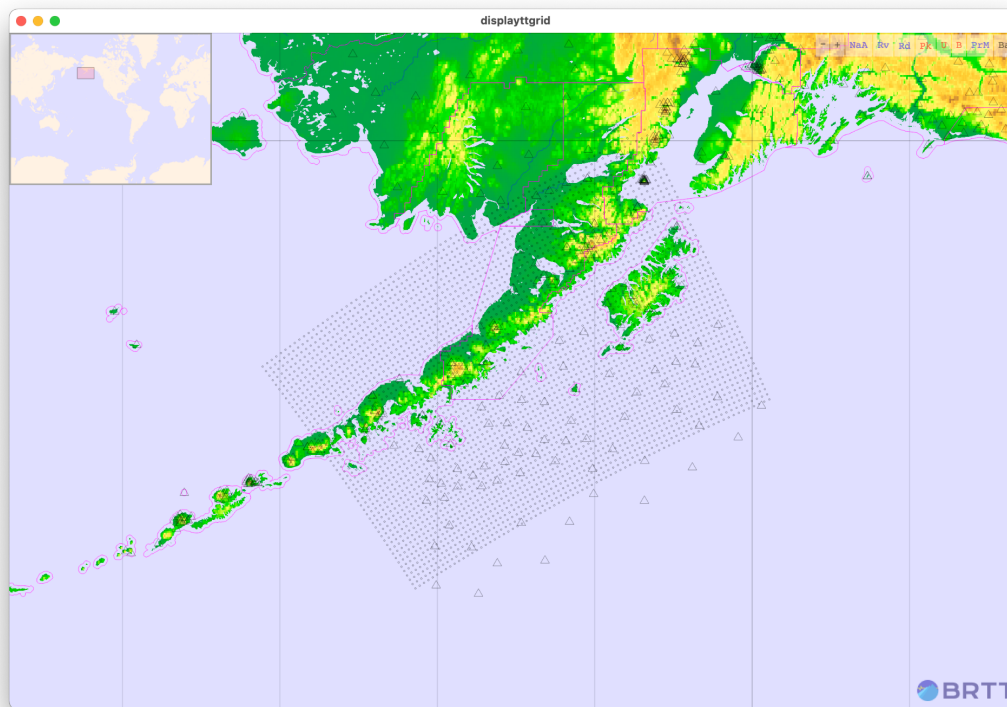


Figure 1. Travel time grids: (a) 0-50 km deep sources, and (b) 60-260 km deep sources.

2.3.2. Earthquake processing

Earthquake data processing was broken into following steps:

- (1) Run STA/LTA detector (*dbdetect*) on all good quality seismic channels in 2 different frequency bands for ocean bottom vs land stations for each UTC day.
- (2) Run event associator (*dbgrassoc*) on computed detections associating with preexisting events from AEC catalog and identifying new events.
- (3) Student analysts manually review all events, new and pre-existing, using *dbloc2* and *dbpick* programs.
- (4) Supervising seismologist verifies student processing and computes magnitudes for all events using in-house, custom *aeic_dbml* program.

Identified event sources fell into the following categories:

- *Pre-existing events* - these would have been already reviewed by an AEC analyst. There were new auto-detections added from AACSE stations. Student analysts reviewed all new auto-picks, added missing arrivals and removed bad arrivals from AACSE stations. They then computed the new location (origin), deleted all pre-existing origins and saved the best reviewed origin.
- *New events* - Usually these would be smaller events that could not be detected with the permanent network stations. Here again we made sure that we added or corrected all good, clear P and S arrivals and removed bad auto-picks. We then computed the new location, deleted all pre-existing origins and saved our best reviewed origin.
- *Other Alaskan events outside of the AACSE region* - We did not process other Alaskan events outside of the study region. The auto locations for such out-of-region events tended to be near the edges of the travel time grids. These events were deleted. We chose to keep some events that after relocation fell slightly outside of the study region.
- *Teleseismic events (coming from outside of Alaska)* - These events had clear, usually low-frequency P arrivals, but no detected S arrivals. The depths for such events also tended to be quite deep (>100 km). These events were deleted.
- *Bogus events* - These were formed from various data glitches or noise bursts. These events were deleted.

We used 4 regional plane-layer velocity models for locations: *gulfak* for events in the Gulf of Alaska and outer rise (Table 1), *northak* for shallow crustal events (Table 2), *pavdut* for events near Shumagin Islands (Table 3), and *scak* for events under Alaska Peninsula and Kodiak Island (Table 4).

The AACSE station network was rolled out gradually over the course of about 2 months between May-July, 2018 and the stations were removed again over the course of about 2 months in August-September, 2019. We processed earthquakes that occurred between May 12, 2018 when the first AACSE stations were installed, through August 31, 2019, about 10 days before the last AACSE station was decommissioned. The mid-May processing start allowed us to get familiar with the network gradually and train student analysts on a dataset with fewer new stations. We chose to end the catalog processing on August 31, 2019 since only a handful of stations operated beyond that date. These stations would have not provided any new

earthquake deceptions and there would have been very few new picks for the existing events, especially compared with the thousands of new picks already added into the catalog.

Table 1. Velocity model *gulfak*.

Depth to top (km)	P velocity (km/s)	S velocity (km/s)
0	5	2.9
7	6.8	3.8
12	8.1	4.5

Table 2. Velocity model *northak*.

Depth to top (km)	P velocity (km/s)	S velocity (km/s)
0	5.9	3.3
24	7.4	4.2
40	7.9	4.4
76	8.29	4.7

Table 3. Velocity model *pavdut*.

Depth to top (km)	P velocity (km/s)	S velocity (km/s)
0	3.05	1.71
3	3.44	1.93
4.79	5.56	3.12
6.65	6.06	3.4
13.18	6.72	3.78
25.63	7.61	4.28
41.51	7.9	4.44

Table 4. Velocity model *scak*.

Depth to top (km)	P velocity (km/s)	S velocity (km/s)
0	5.3	3.0
4	5.6	3.1
10	6.2	3.5
15	6.9	3.9
20	7.4	4.2
25	7.7	4.3
33	7.9	4.4
47	8.1	4.5
65	8.3	4.7

2.3.3. Processing challenges

As we went along with the data analysis, we encountered a few challenges. Many stations had data quality issues, such as glitches on some or all components, timing problems, pegged mass positions, especially further in time into the project. Fortunately, some stations had both broadband and strong motion sensors, as well as pressure gauges. Our first choice for phase picks at any station was always a broadband sensor, vertical channels for P-wave picks and horizontal channels for S-wave picks. If for any reason arrivals on broadband channels were impossible to discern, we used strong motion (P and/or S arrivals) or pressure (only P

arrivals) data channels. As much as possible, we tried to avoid picking on stations with reported timing problems, but we suspect a few picks from such stations still made it into the catalog. For processing, we used the same filters as for auto-detections.

Due to strong velocity heterogeneities some OBS stations had small amplitude, emergent arrivals on vertical channels that were not discernable on horizontal channels. As a result, we chose not to pick P arrivals on horizontal channels of OBS stations, while we occasionally used horizontal channels for P picks on land stations. We also occasionally used vertical channels to pick S arrivals on both OBS and land sites.

Lastly, strong structural heterogeneities resulted in high RMS residuals for some events, especially those with many OBS stations in the solutions. We chose to keep all picks, even with high travel time residuals, rather than removing them to lower the overall RMS. At times we had to fix depth or epicenter when we could not obtain a reasonable solution with free depth.

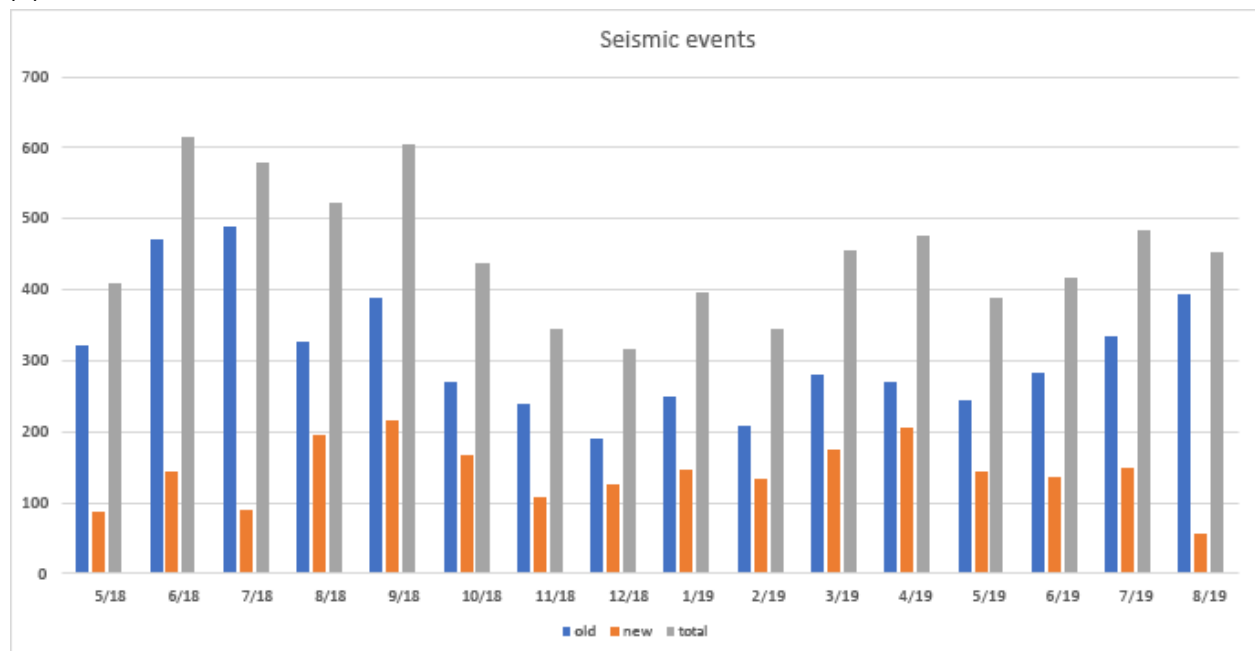
2.4. Compiling and distributing earthquake catalog

We analyzed 7,242 earthquakes, 2,279 of which (or 39%) were newly identified events with nearly 440,000 seismic phases total, almost 300,000 of which (or 60%) were new picks (Figure 2a-b, Figure 3a, Table 5). Most of the newly detected earthquakes were in the M7.9 2018 Offshore Kodiak earthquake aftershock region, as well as under the Kodiak Island and the Alaska Peninsula (Figure 3b, Figure 4). Figure 5 shows the cumulative number of earthquakes from the AEC catalog superimposed on the cumulative number in the AACSE catalog. Figure 6 shows the number of phase picks in the AEC catalog superimposed on the number of picks in the AACSE catalog.

The largest recorded earthquakes were M6.1 on December 31, 2018 and M5.9 on July 19, 2018 under Shumagin Islands, and M5.9 on May 27, 2019 under Kodiak Island. Time-magnitude plot is shown in Figure 7.

After processing, original CSS Datascope tables were converted into *quakeml* format and uploaded to the USGS's Comcat catalog as AACSE catalog with AK contributor. We also made available monthly Datascope CSS3.0 database tables and *quakeml* files with UA@ScholarWorks publications.

(a)



(b)

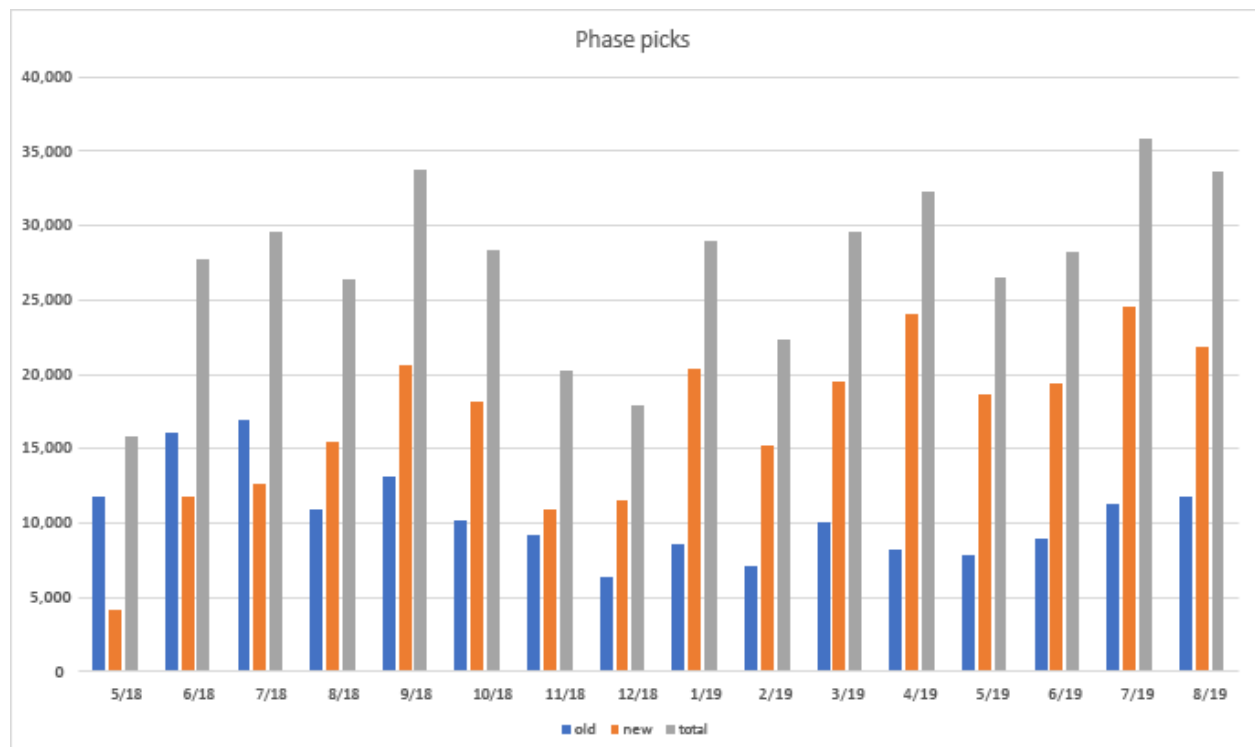
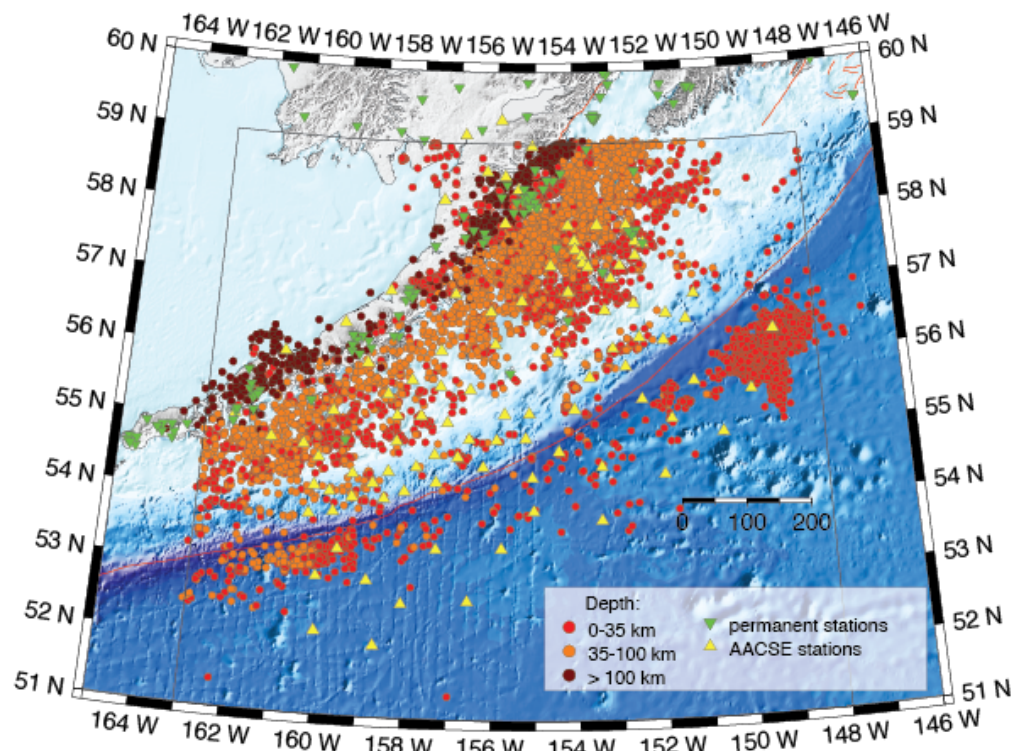


Figure 2. Monthly breakdown by new, old and total of (a) analyzed seismic events and (b) picked seismic phases.

Table 5. Monthly breakdown of analyzed events and picked seismic phases.

	Events				Picks			
Year-Month	Old	New	Total	Percent new	Old	New	Total	Percent new
2018-05	322	87	409	21	11,727	4,129	15,856	26
2018-06	471	145	616	24	16,034	11,734	27,768	42
2018-07	488	90	578	16	16,936	12,690	29,626	43
2018-08	327	195	522	37	10,906	15,463	26,369	59
2018-09	389	215	604	36	13,115	20,576	33,691	61
2018-10	271	166	437	38	10,149	18,202	28,351	64
2018-11	239	107	346	31	9,231	10,966	20,197	54
2018-12	190	127	317	40	6,354	11,565	17,919	65
2019-01	250	147	397	37	8,630	20,357	28,987	70
2019-02	209	135	344	39	7,054	15,232	22,286	68
2019-03	280	175	455	38	10,040	19,565	29,605	66
2019-04	271	205	476	43	8,259	24,058	32,317	74
2019-05	245	143	388	37	7,831	18,700	26,531	70
2019-06	282	136	418	33	8,901	19,358	28,259	69
2019-07	334	149	483	31	11,342	24,545	35,887	68
2019-08	390	63	452	14	11,763	17,610	29,373	60
Total	4,958	2,285	7,243	32	168,272	264,850	433,122	61

(a)



(b)

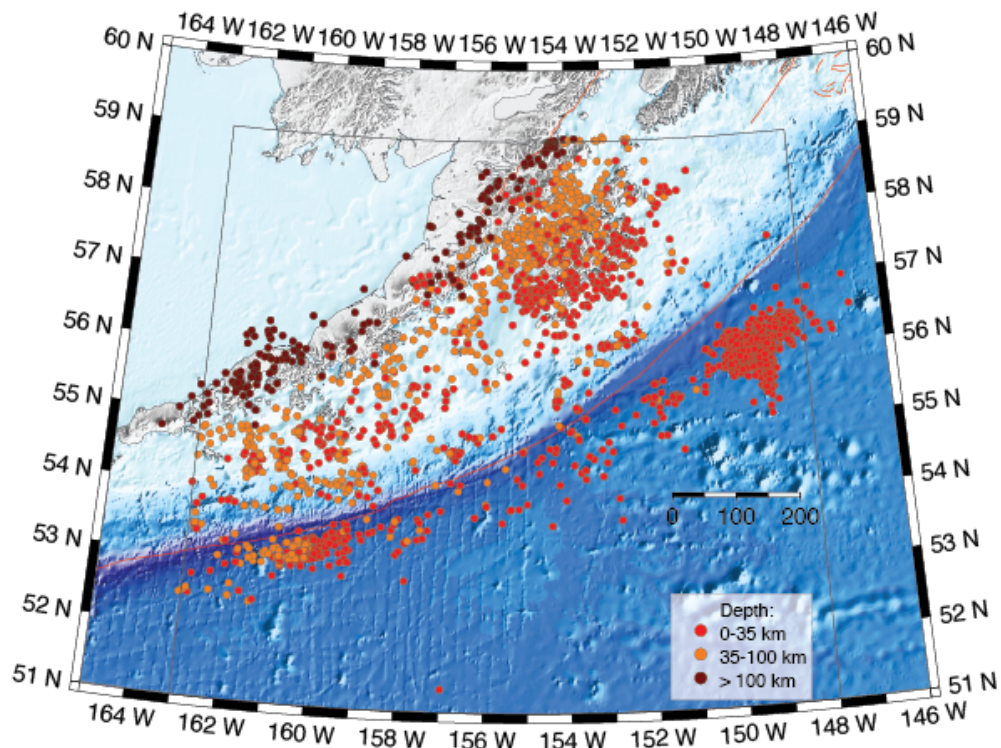
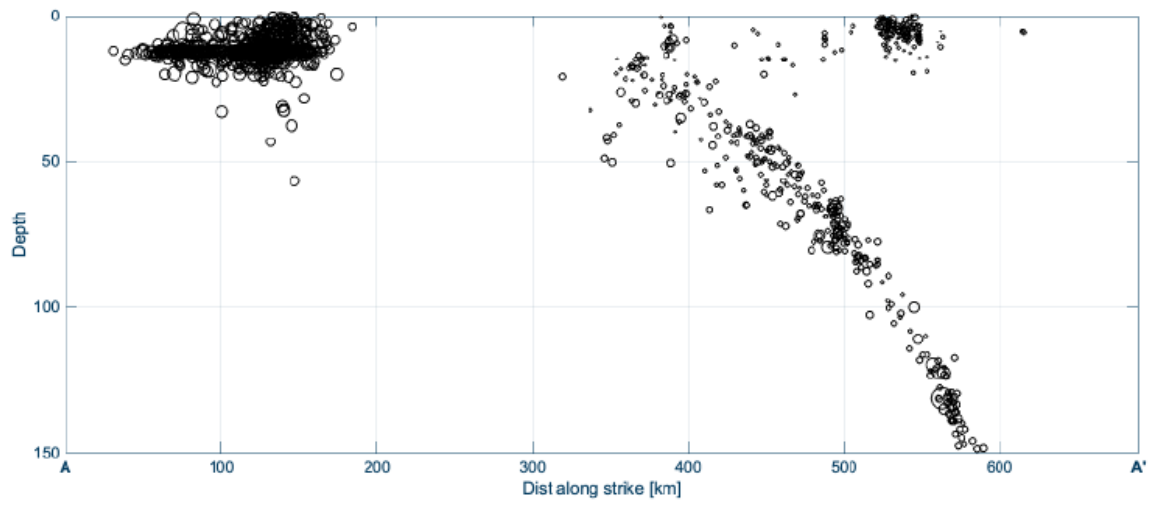


Figure 3. Map of (a) all processed events and (b) newly detected events, color-coded by depth. AACSE and permanent seismic stations are shown in (a).

(a)



(b)

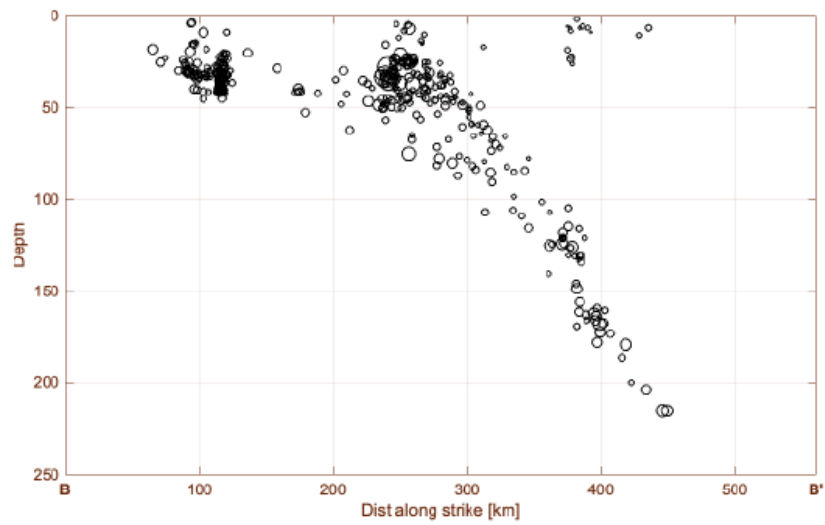


Figure 4. Cross-sections under (a) Kodiak Island and (b) Shumagin Islands. Vertical scale is exaggerated.

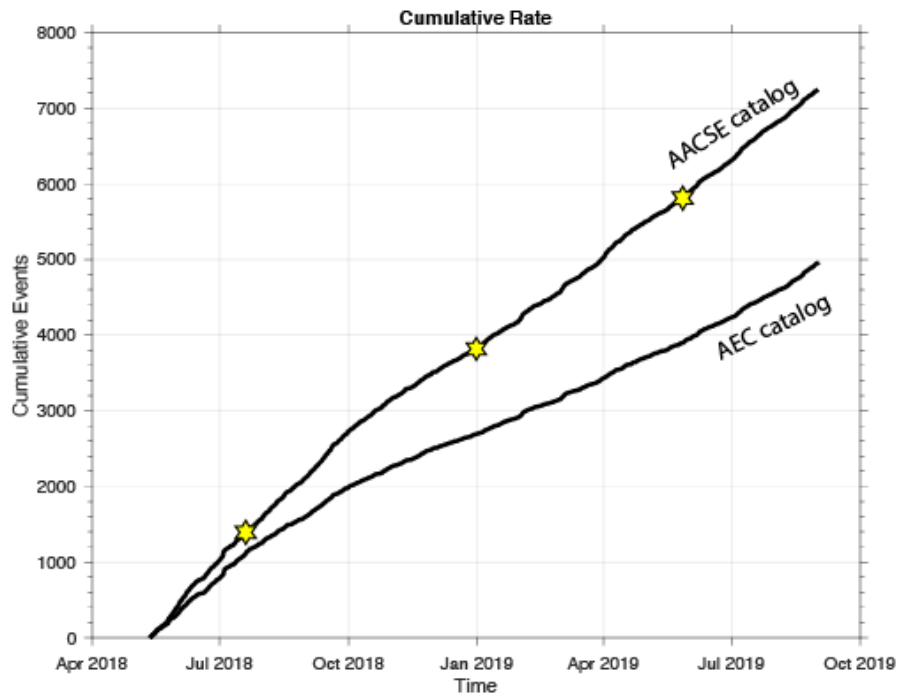


Figure 5. Cumulative number of earthquakes from the AEC catalog superimposed on cumulative number in the AACSE catalog. Yellow stars indicate occurrence of the 3 largest earthquakes.

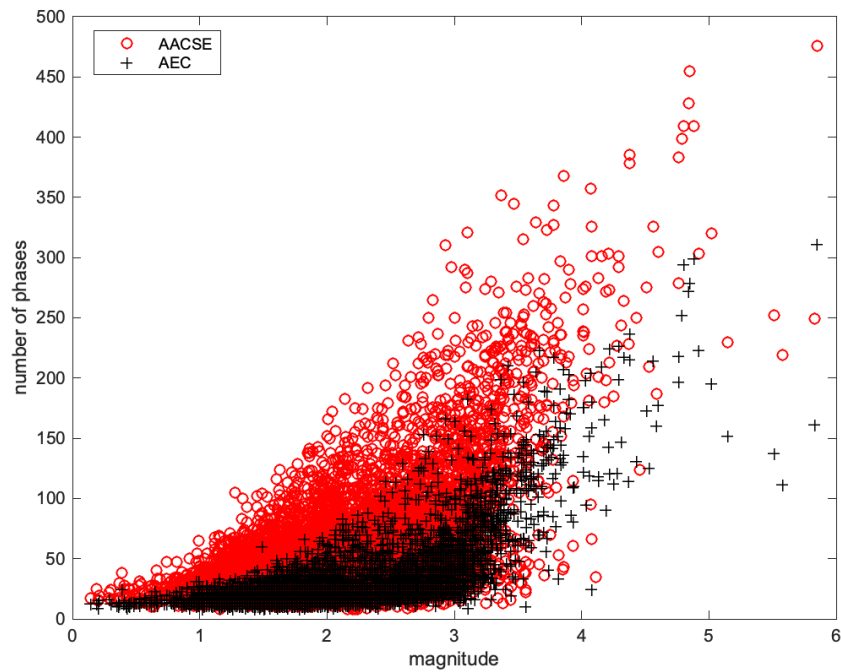


Figure 6. Number of phase picks in the AEC catalog (black crosses) superimposed on number of picks in the AACSE catalog (red circles).

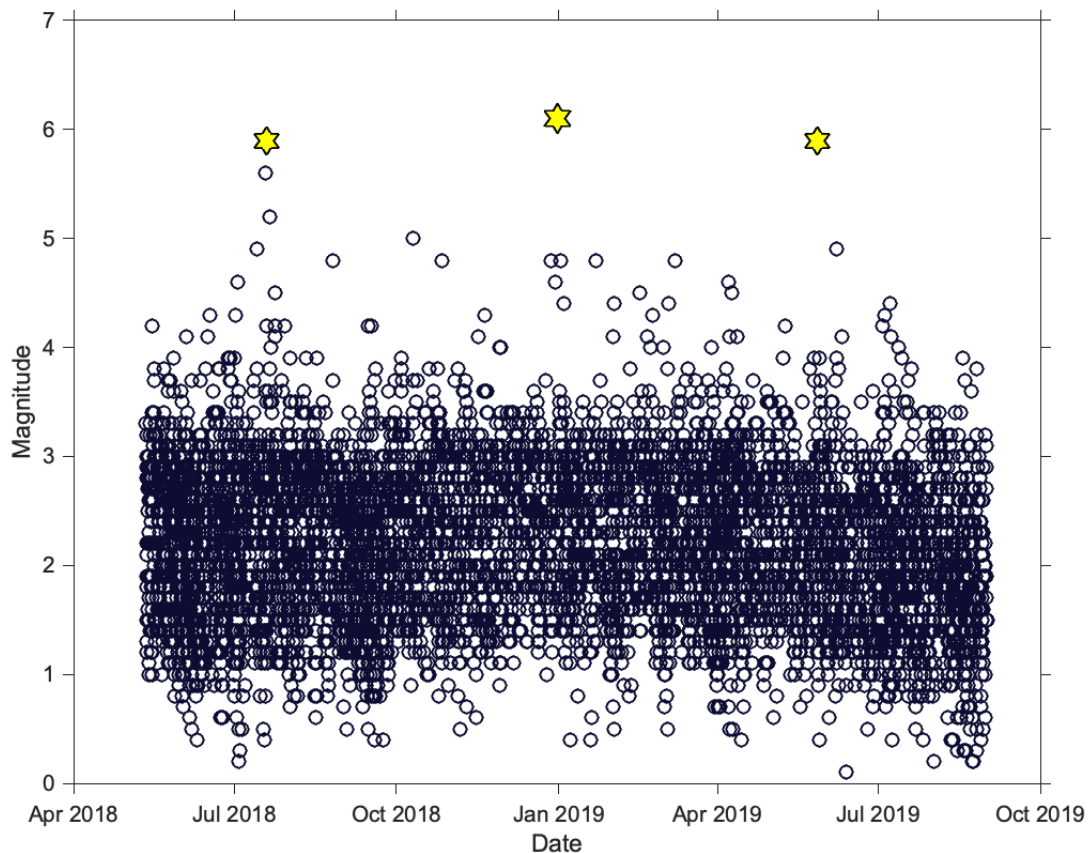


Figure 7. Time-magnitude plot of all analyzed events. The largest recorded earthquakes were M6.1 on December 31, 2018 and M5.9 on July 19, 2018 under Shumagin Islands, and M5.9 on May 27, 2019 under Kodiak Island.

Project data

Earthquake catalog and phase picks are available from the ANSS Comprehensive Earthquake catalog (Comcat, <https://earthquake.usgs.gov/data/comcat/>). Monthly CSS Datascope tables and *quakeml* files are available from UA@Scholarworks (Ruppert et al., 2021a, 2021b).

Bibliography

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